APPENDIX F

COMPUTATION FOR DESIGN OF OUTLET WORKS STILLING BASIN
(Illustrative Examples)

F-1. Introduction. The following detailed examples are presented to illustrate the procedures for the design of outlet works stilling basin discussed in Chapter 5. Two examples with different tailwater and exit channel elevations are used to illustrate a normal design and a design for a low-level outlet with respect to tailwater where eddy problems within the
* stilling basin are likely to occur. (Note: These calculations may also be performed using the computer program H2261, Stilling Basin Design for Conduit Outlet Works, found in the USAE computer program library, CORPS.) *

F-2. Design Conditions. The following information is used for design example:

Conduit diameter D = 14 ft
Conduit slope S = 0.01 ft/ft ($\theta = 0° \; 34.5' = 0.573°$)
Design discharge Q = 12,320 cfs (for smooth pipe and design pool)
Elevation outlet portal invert = 100 ft msl

Case 1:

Exit channel invert elevation = 90 ft msl
Tailwater rating curve shown in plate F-1

Case 2:

Exit channel invert elevation = 98 ft msl
Tailwater rating curve shown in plate F-1

F-3. Design Computations.

a. Transition Sidewall Flare.

$$\text{Conduit area } A = \frac{\pi D^2}{4} = \frac{3.14(14)^2}{4} = 154 \text{ ft}^2$$

$Q = 12{,}320$ cfs; $V_{sm} = 80.0$ fps

$$\mathbb{F} = \frac{V_{sm}}{\sqrt{gD}} = \frac{80.0}{\sqrt{32.2(14)}} = 3.77$$

From equation 5-2, paragraph 5-2d

$$\Delta L = 2\ \mathbb{F} = 2(3.77) = 7.54 \qquad \text{Since } \Delta L>6, \text{ use } \Delta L = 7.54$$

b. Radius to Connect Outlet to Sidewall. The shape change from circular to rectangular cross section will be made with free surface flow.

$$R = 5D = 5(14) = 70 \text{ ft}$$

$$L_t = \text{tangent length} = R \tan\frac{\phi}{2} = 70 \tan\left(\frac{1}{2}\text{ Arc tan } \frac{1}{7.54}\right) = 4.61'$$

c. Length of Fillets.

$$L_f = 1.5D = 1.5(14) = 21 \text{ ft}$$

Therefore invert must continue on slope of conduit (0.01 ft/ft) for a distance of 21 ft.

d. Parabolic Invert Drop. Using equation 5-3 paragraph 5-2d(3).

$$y = -x \tan\theta - \frac{gx^2}{2\left(1.25\ V_{sm}\right)^2 \cos^2\theta}$$

$$1.25\ V_{sm} = 100 \text{ fps}$$

therefore

$$y = -x \tan 0.573° - \frac{32.2x^2}{2\left(100\right)^2 \cos^2 0.573°}$$

or

$$y = -0.01x - 0.00161x^2$$

e. Case 1 Design.

(1) Stilling Basin Geometry. From plate F-1, the tailwater elevation at design discharge (12,320 cfs) is 100.2 ft msl. Assume various basin apron elevations and compute basin width (W_b), entering flow depth (d_1),
* entering flow velocity (V_1), Froude number of entering flow ($\mathbb{F}_1$), required downstream depth to force jump (d_2), $0.85d_2$ and actual depth from apron floor to tailwater water surface (d). Assume energy losses between outlet portal and basin apron are negligible, i.e.,

$$\frac{V^2}{2g} + y_p = \frac{V_1^2}{2g} + d_1 - \text{(Outlet el - Apron el)}$$

where y_p = height of pressure grade line at exit portal (plate C-3)

$= 0.57D = 0.57(14) = 8.0$ ft

and

$$d_1 = \frac{Q}{V_1 W_b}$$

Also $$W_b = D + \frac{2(X+L_f-L_t)}{\Delta L} = 14 + \frac{2(X+21-4.61)}{7.54} = 14 + \frac{X+16.39}{3.77}$$

where X is determined from the parabolic equation after Y is determined from assumed apron elevation. This can be simplified by making a plot of x versus y for the parabolic invert drop equation (plate F-2).

Then $-Y$ = El outlet $- S(L_f)$ - Apron El

= 100 - 0.21 - Apron El = 99.79 - Apron El

Table F-1

Computations for Determining Basin Apron Elevation (Case 1)

(1) Q cfs	(2) Apron El msl	(3) Y ft	(4) X ft	(5) W_b ft	(6) V_1 fps	(7) d_1 ft	(8) $\mathbb{F}_1$	(9) d_2 ft	(10) $0.85d_2$ ft	(11) Actual d ft
12,320	80	-19.79	107.84	46.96	89.55	2.93	9.22	36.76	31.25	20.20
12,320	65	-34.79	143.98	56.54	95.01	2.29	11.06	34.73	29.52	35.20
12,320	70	-29.79	133.00	53.63	93.25	2.46	10.47	35.26	29.97	30.20
									O.K.	
Check jump with lesser discharges										
8,000	70	-29.79	133.00	53.63	71.16	2.10	8.66	24.65	20.95	30.20
4,000*	70	-29.79	133.00	53.63	59.82	1.25	9.44	16.04	13.63	26.2

NOTE: See explanatory notes on page F-4.

Explanatory Notes for Table F-1

(1) Design discharge (* Denotes partially full conduit flow condition, $Q_{full} = 4408$ cfs)

(2) Assumed value of apron el

(3) Computed from $-Y$ = El outlet $- S(L_f)$ - Apron El

(4) With computed value of Y (Step 3) compute X

$$Y = -X \tan \theta - \frac{gX^2}{2(1.25V)^2 \cos^2\theta}$$ *

Solve by quadratic formula, graphically or numerically

(5) Width of stilling basin

$$W_b = D + \frac{2(X+L_f-L_t)}{\Delta L}$$ *

(6) Flow velocity in stilling basin at section 1

$$\frac{V^2}{2g} + y_p = \frac{V_1^2}{2g} + \frac{Q}{V_1 W_b} - (\text{Outlet el} - \text{Apron el})$$

Solve for V_1 either graphically or numerically (cubic equation).

(7) Flow depth at section 1

$$d_1 = \frac{Q}{V_1 W_b}$$

(8) Froude number of flow at section 1

$$\mathbb{F}_1 = \frac{V_1}{\sqrt{gd_1}}$$

(9) Sequent depth in stilling basin at section 2

$$d_2 = \frac{d_1}{2}\left(\sqrt{1 + 8\,\mathbb{F}_1^2} - 1\right)$$ *

(10) Sequent depth (d_2) multiplied by 0.85

(11) Actual depth at section 2

d = Tailwater el - Apron el

Results:

Stilling basin apron elevation = 70 ft msl
Stilling basin width W_b = 53.6 ft
Transition Length = $L_f + X$ = 154 ft
Stilling basin length $L_B = 3d_2 = 3(35.26)$ = 105.8 or 106 ft

(2) Baffle Piers. Since the stilling basin apron elevation was set at $0.86\ d_2$ for tailwater at the design discharge, two rows of baffle piers should be used.

Height of baffle piers $d_1 = 2.46$ ft; say 2.5 ft.
(Check $1/6d_2 = 35.26/6 = 5.48$ ft $\therefore$ 2.5 ft o.k.)

Since velocity entering basin is greater than 60 fps, first row of baffles should be placed farther than $1.5d_2$ downstream from toe of parabolic drop. Since $1.5d_2 = 1.5(35.26) = 52.9$ ft, place first row of baffles 60 ft downstream. This is based on judgment depending on flow velocity entering basin. Second row should be approximately $0.5d_2$ farther downstream, or $0.5d_2 = 0.5(35.26) = 17.6$ ft . Thus, place second row 18 ft downstream from first row. Make width of baffles and spacing equal to baffle height or 2.5 ft.

(3) End Sill. The height of end sill should be half of the baffle height or $0.5(2.5) = 1.25$ ft , and the upstream face should have a IV-on-1H slope.

(4) Determination If Low-Level Outlet. Check to determine if conduit outlet portal is low with respect to tailwater for low flows. Determine section in the transition where parabolic invert slope is IV on 6H.

$$y = -0.01x - 0.00161x^2$$

thus

$$\frac{dy}{dx} = -0.01 - 0.00322x = -\frac{1}{6} = -0.1667$$

or

$$x = 48.66 \text{ ft}$$

and

$$y = -4.3 \text{ ft}$$

Thus, invert elevation of section is 100.00 - 0.21 - 4.30 = 95.49 ft msl, and the local width of basin on the sloping apron $W_s = 14 + (48.66 + 16.39)/3.77 = 31.25$ ft . Computed d_2 elevations for lesser discharges and the corresponding tailwater elevations are compared in table F-2. The d_2 elevations are well above the tailwater elevations and there should be no eddy problems in the stilling basin.

Table F-2

TAILWATER ELEVATION VERSUS d_2 ELEVATION FOR LOW FLOWS

(1) Q cfs	(2) d ft	(3) V fps	(4) W_s ft	(5) V_s fps	(6) d_{1_s} ft	(7) $\mathbb{F}_1$	(8) d_{2_s} ft	(9) El d_2 msl	(10-1) Case 1 TW El msl	(10-2) Case 2 TW El msl
500*	3.18	19.03	31.25	28.66	0.56	6.76	5.06	100.55	91.5	101.3
1,000*	4.53	23.19	31.25	32.51	0.98	5.77	7.56	103.05	92.5	103.2
1,500*	5.63	25.90	31.25	35.16	1.37	5.30	9.58	105.07	93.2	104.2

Explanatory Notes for Table F-2

(1) Low flow discharge (* Denotes partially full flow condition, Q_{full} = 4408 cfs)

(2) Normal depth for assumed discharge (assuming n = 0.012)

(3) Normal velocity, $V = Q/A$ where A is area of flow for the computed normal depth

(4) Width of transition at point where invert slope equals 1/6

$$W_s = D + \frac{2(x+L_f-L_t)}{\Delta L}$$

where x = 48.66 ft , L_f = 21 ft , L_t = 4.61 ft and ΔL = 7.54 ft

(5) Flow velocity at section where slope equals 1/6

$$\frac{V^2}{2g} + d = \frac{V_s^2}{2g} + \frac{Q}{V_s W_s} - (\text{Outlet el} - \text{Invert el at section})$$

Solve for V_s either graphically or numerically (cubic equation)

(6) Flow depth at section where slope invert slope equals 1/6

$$d_{1_s} = \frac{Q}{V_s W_s}$$

(7) Froude number of flow at section where invert slope equals 1/6

$$\mathbb{F}_1 = \frac{V_s}{\sqrt{g d_{1_s}}}$$

(8) Sequent depth of d_{1_s} at section where invert slope equals 1/6

$$d_{2_s} = \frac{d_{1_s}}{2}\left(\sqrt{1 + 8\,\mathbb{F}_1^2} - 1\right)$$

(9) Water-surface elevation corresponding to alternate depth at section where invert slope equals 1/6

$$\text{EL } d_2 = 95.49 + d_{2_s}$$

(10) Tailwater elevation corresponding to given discharge (Case 1 and Case 2).

(5) Riprap Design. The average velocity over the end sill is used in HDC 712-1[n] to determine minimum riprap size (W_{50} and/or D_{50}).

$$V = \frac{Q}{A} = \frac{12,320}{53.6\ (30.2 - 1.5)} = 8.0 \text{ fps}$$

From HDC 712-1[n] with specific weight of stone of 165 lb/ft^3 and V = * 8.0 fps , W_{50} = 45 lb and D_{50} = 0.80 ft or 9.6 in. ; use D_{50} = 12 in. * or greater. The extent of riprap downstream depends on local scour conditions and exit channel configuration. Details of the stilling basin and recommended outlet channel configuration are shown in plates F-3 and F-4, respectively.

f. Case 2 Design.

(1) Stilling Basin Geometry. From plate F-1, the tailwater elevation at design discharge (12,320 cfs) is 118.6 ft msl. Assume various basin apron elevations and make computations as in paragraph F-3c above and similar to table F-1.

Table F-3
Computations for Determining Basin Apron Elevation (Case 2)

(1) Q cfs	(2) Apron El msl	(3) Y ft	(4) X ft	(5) W_b ft	(6) V_1 fps	(7) d_1 ft	(8) F_1	(9) d_2 ft	(10) $0.85d_2$ ft	(11) Actual d ft
12,320	80	-19.79	107.84	46.96	89.55	2.93	9.22	36.76	31.25	38.60
12,320	90	- 9.79	74.96	38.23	85.57	3.77	7.77	39.54	33.61	28.60
12,320	86	-13.79	89.53	42.10	87.21	3.36	8.39	38.17	32.46 O.K.	32.60
Check jump with lesser discharges										
8,000	86	-13.79	89.53	42.10	63.05	3.01	6.40	25.81	21.94	29.50
4,000*	86	-13.79	89.53	42.10	50.06	1.90	6.40	16.26	13.82	23.20

* Denotes partially full flow condition, Q_{full} = 4,408 cfs.

(Same column-by-column description (explanatory notes) as table F-1.)

Thus,

Stilling basin apron elevation = 86 ft msl
Stilling basin width W_b = 42.1 ft

Transition length = $L_f + X = 1.5D + X = 110.5$ ft
Stilling basin length $L_B = 3d_2 = 3(38.17) = 114.5$ or 115 ft

(2) Baffle Piers.

Height of baffle piers = d_1 = 3.36 ft, say 3.5 ft.

(Check $1/6d_2$ = 38.17/6 = 6.36 ft ∴ 3.5 ft o.k.)

Since velocity entering basin is greater than 60 fps, first row of baffles should be placed farther than $1.5d_2$ downstream from toe of parabolic drop, i.e.,

$$1.5d_2 = 1.5(38.17) = 57.3 \text{ ft}$$

Therefore, place first row 65 ft downstream from toe of transition. Second row should be approximately $0.5d_2$ farther downstream or

$$0.5d_2 = 0.5(38.17) = 19.1, \text{ say } 20 \text{ ft}$$

Make width and spacing equal to baffle height or 3.5 ft

(3) End Sill. The height of end sill should be half of the baffle height or 0.5(3.5) = 1.75 ft , and the upstream face should have a 1V-on-1H slope.

(4) Determination If Low-Level Outlet. Check to determine if outlet portal is low with respect to tailwater for low flows as for Case 1. The section in the transition where the invert slope was equal to 1V on 6H was at x = 48.66 ft , y = 4.3 ft , and invert elevation was 95.49 ft msl. (Case 1 - para F-3e(4)). The tailwater rating curve for Case 2 (plate F-1) indicates that the tailwater elevations for lesser discharges are considerably higher than 95.49, therefore, check d_2 elevation versus tailwater elevations for several low flows as in table F-2. Since the tailwater elevation is above the elevation of d_2 at the section where the slope is 1V on 6H for discharges of approximately 1100 cfs and less, an eddy problem
* is likely to occur with these low flows. Thus, an inverted V is needed along the center line of the trajectory. The center-line elevation of the inverted V at a distance L_f downstream from the outlet portal is 100 + 0.19D = 100 + 2.66 = 102.66. Thus, y = 102.66 - 86 (stilling basin apron elevation) = 16.66 ft and x = 89.5 ft from $y' = -C_m X^2$

$$C_m = \frac{16.66}{(89.5)^2} = 0.0021$$

Thus, the equation of the center-line trajectory will be $y' = -0.0021\,x^2$. *
The trajectory is shown on Plate F-5.

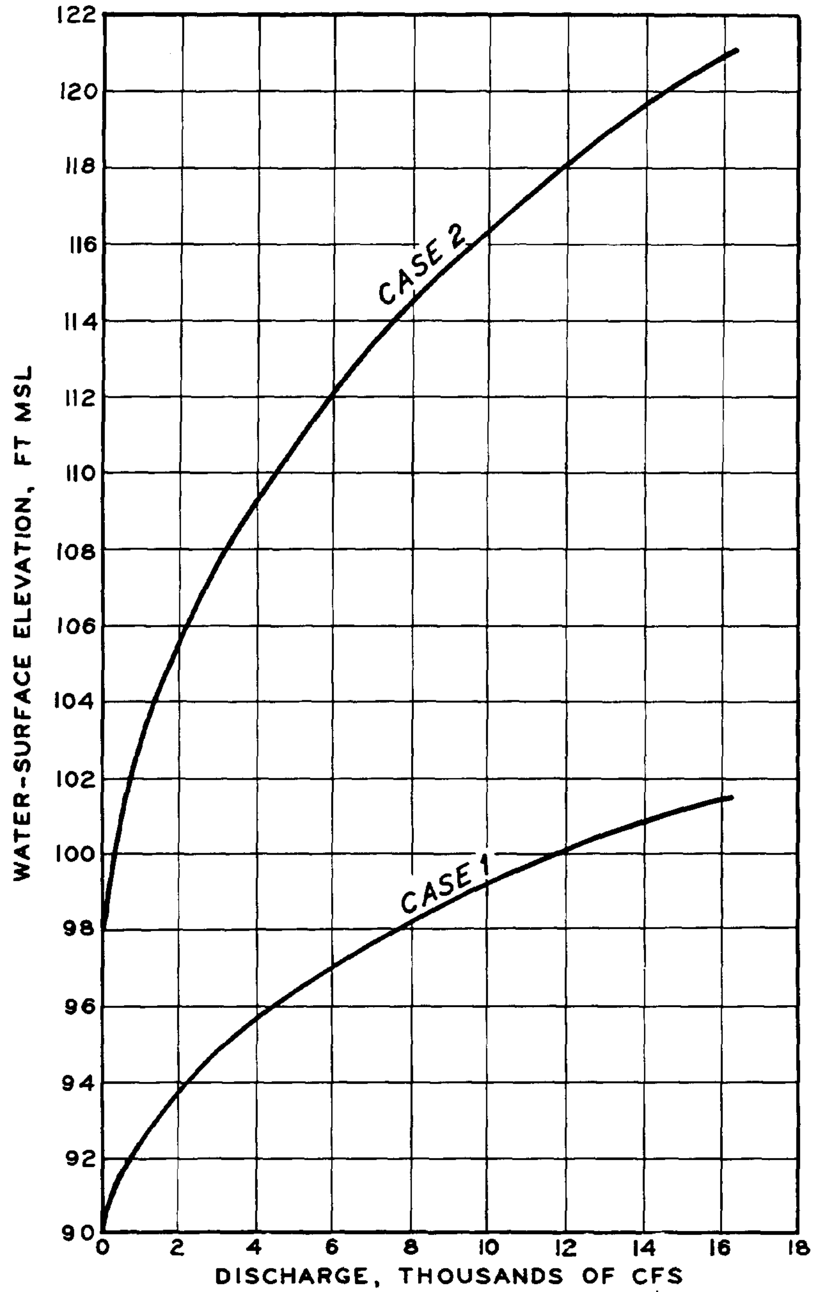
(5) Riprap Design.

Average velocity over end sill = $\frac{Q}{A} = \frac{12,320}{42.1(32.6 - 2.0)} = 9.6$ fps

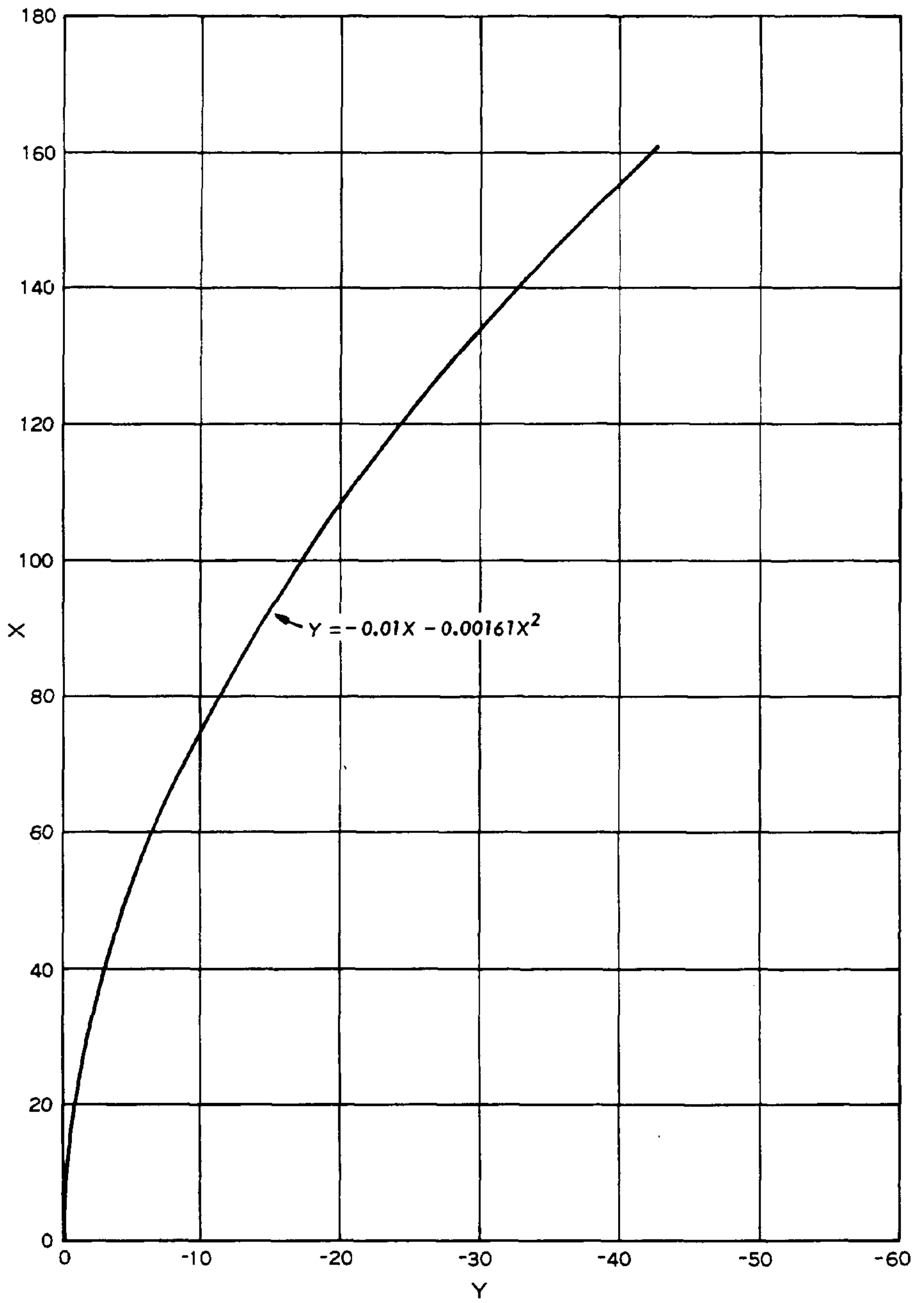
From HDC 712-1[n] W_{50} = 135 lb, D_{50} = 1.16 ft or 13.9 in.

* Use D_{50} = 15 in. or larger *

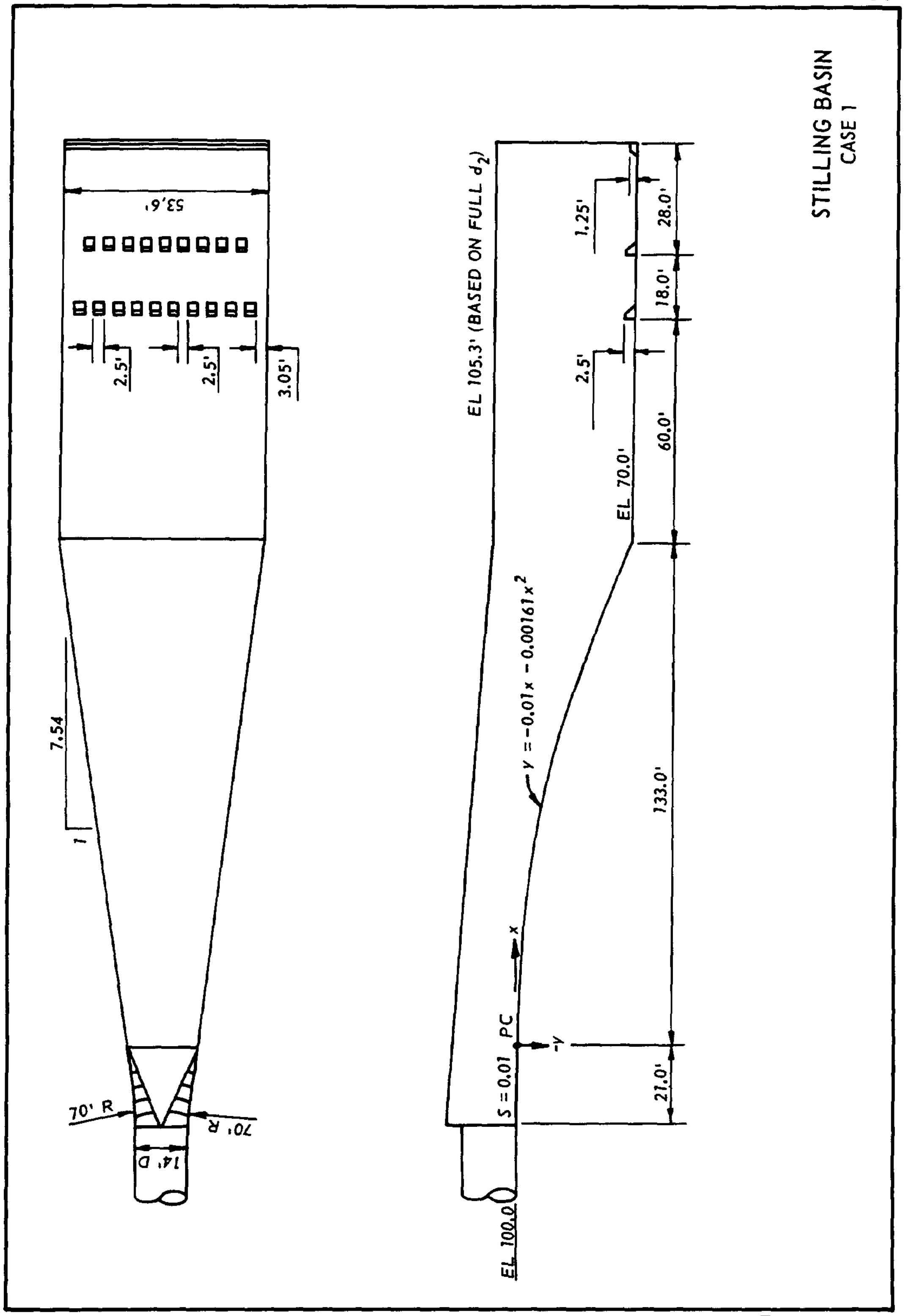
Details of stilling basin and outlet channel are shown in plates F-5 and F-6.

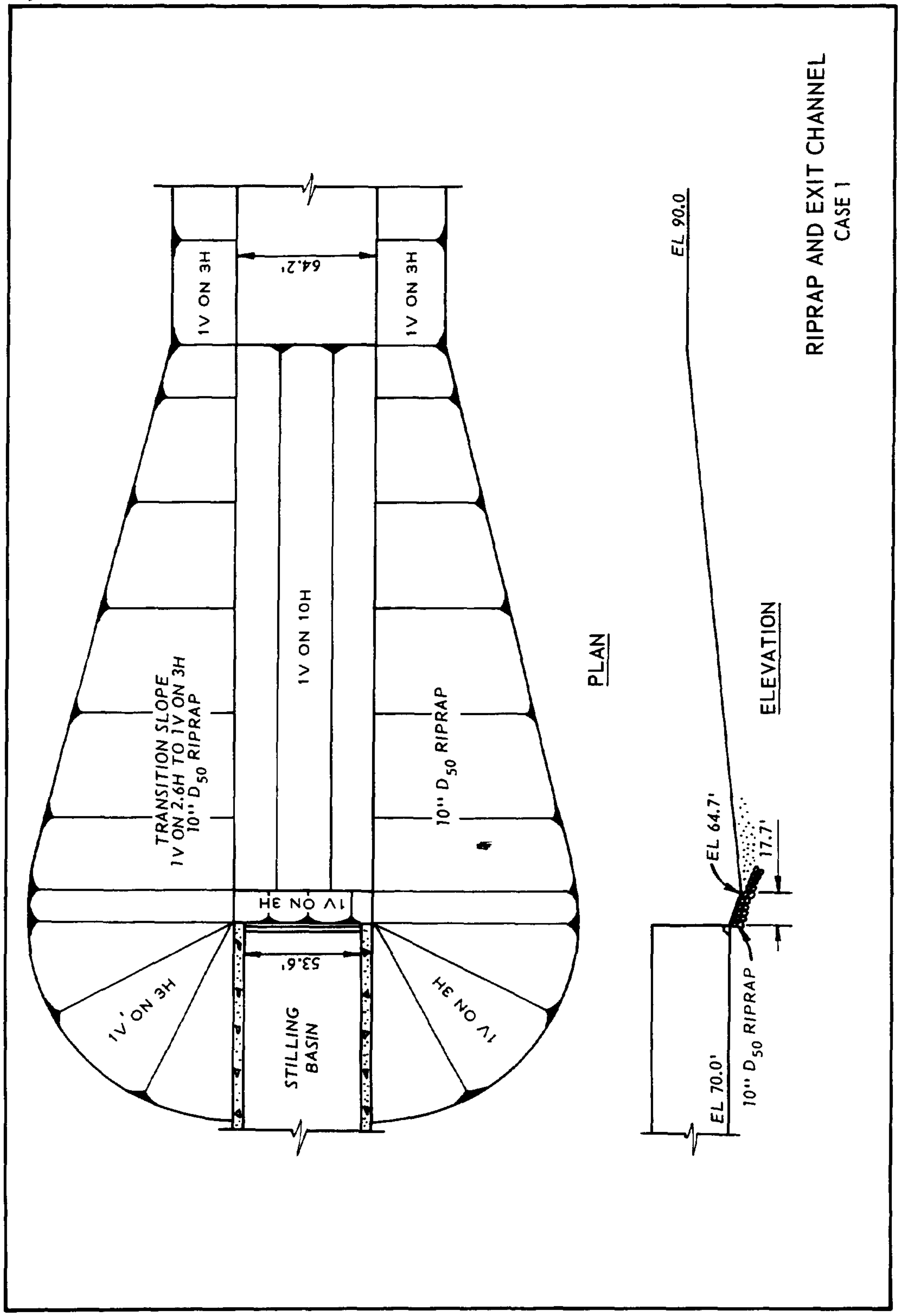


TAILWATER RATING CURVE

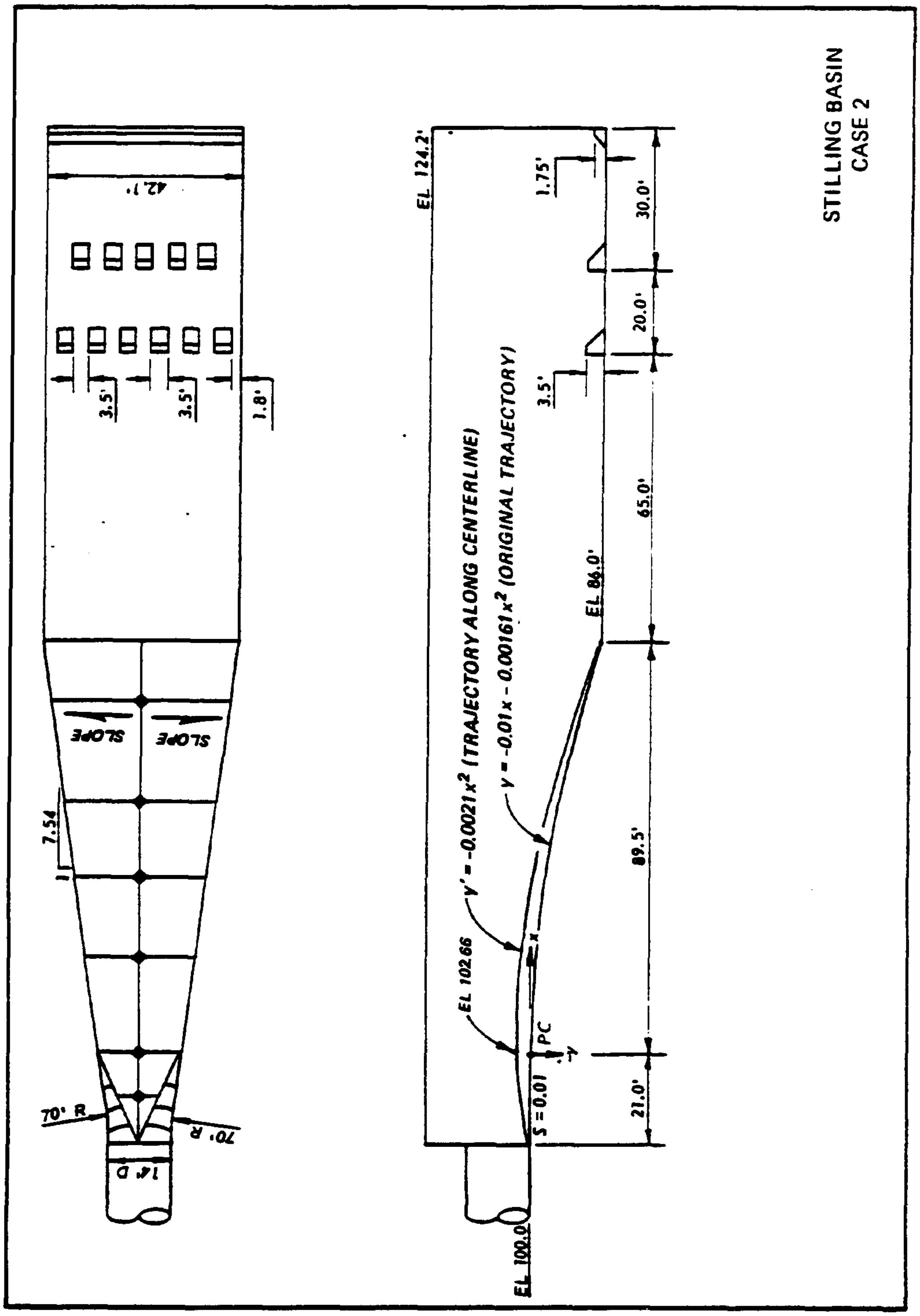


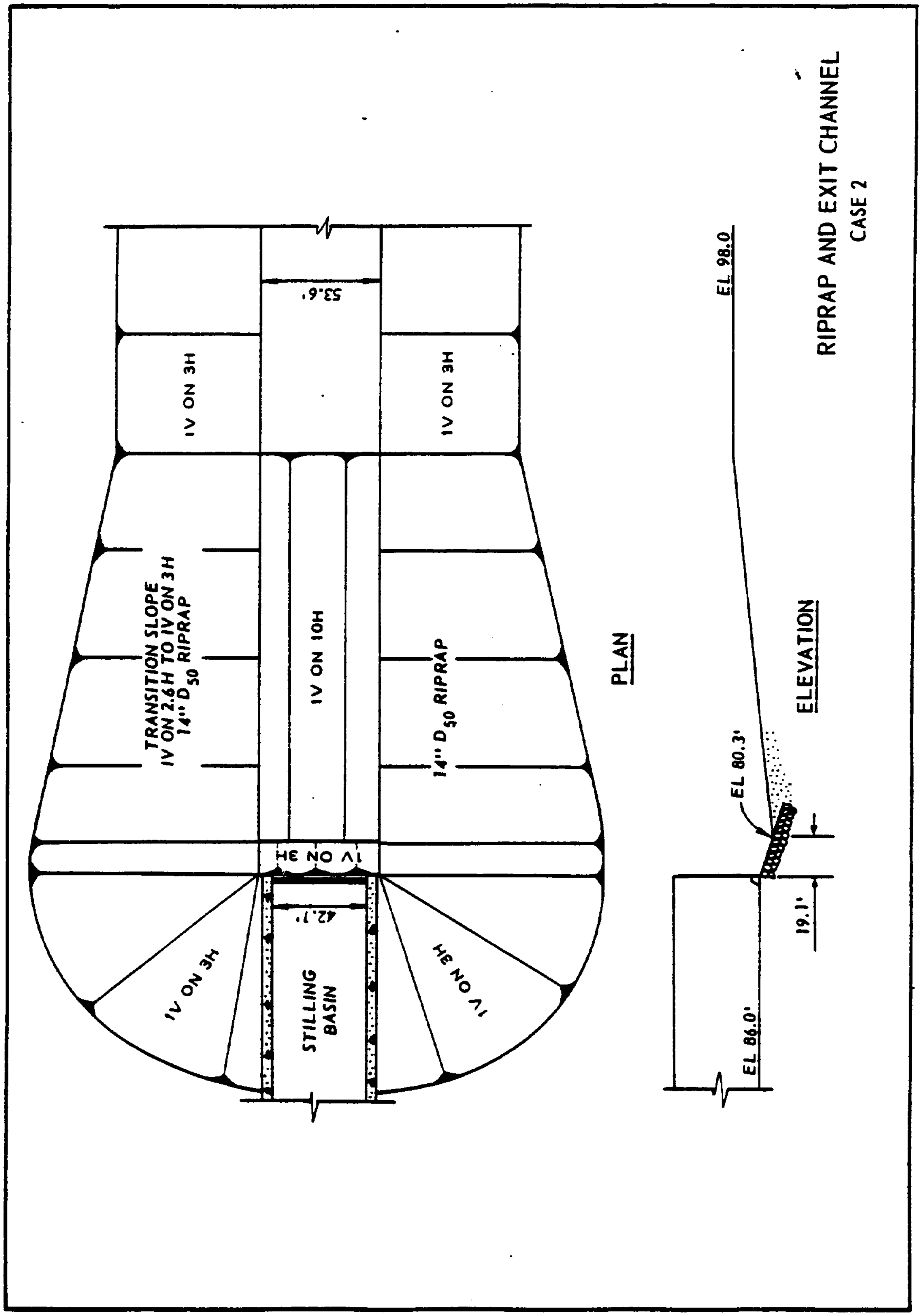
PARABOLIC INVERT
TRANSITION CURVE


STILLING BASIN
CASE 1
53.6'
2.5'
2.5'
3.05'
7.54
1
70' R
70' R
14' D
EL 105.3' (BASED ON FULL d_2)
1.25'
28.0'
18.0'
2.5'
60.0'
EL 70.0'
133.0'
$Y = -0.01x - 0.00161x^2$
x
PC
-Y
S = 0.01
21.0'
EL 100.0



RIPRAP AND EXIT CHANNEL
CASE 1


STILLING BASIN
CASE 2
42.1'
3.5'
3.5'
1.8'
SLOPE
SLOPE
7.54
70' R
70' R
14' D
EL 124.2'
1.75'
30.0'
20.0'
3.5'
65.0'
EL 86.0'
Y' = -0.0021x² (TRAJECTORY ALONG CENTERLINE)
Y = -0.01x - 0.00161x² (ORIGINAL TRAJECTORY)
89.5'
EL 102.66
PC
S = 0.01
21.0'
EL 100.0


RIPRAP AND EXIT CHANNEL
CASE 2
PLAN
ELEVATION
53.6'
1V ON 3H
1V ON 3H
TRANSITION SLOPE
1V ON 2.6H TO 1V ON 3H
14" D50 RIPRAP
1V ON 10H
14" D50 RIPRAP
1V ON 3H
42.1'
STILLING
BASIN
1V ON 3H
1V ON 3H
EL 98.0
EL 80.3'
19.1'
EL 86.0'